


6.170 Lecture 12 Debugging



MIT EECS

Michael Ernst
Saman Amarasinghe

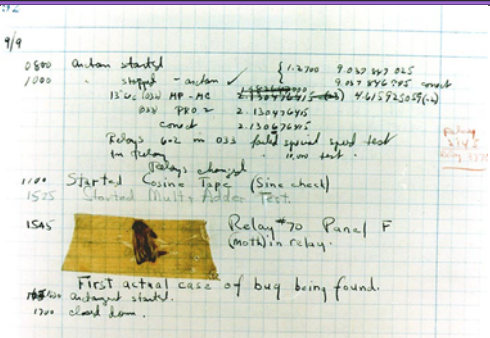
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three related notions

- Validation**
Purpose is to uncover problems and increase confidence
Combination of reasoning and test
- Debugging**
Finding out why a program is not functioning as intended
- Defensive programming**
Programming with validation and debugging in mind
- Testing \neq debugging**
 - test: reveals existence of problem
 - debug: pinpoint location+cause of problem

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a bug – September 9, 1947



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defense in depth

- First defense against bugs is to not make them**
Correctness: get things right first time
- Second defense is to make bugs immediately visible**
Local visibility of errors: if things fail, we'd rather they fail loudly and immediately – e.g. checkRep()
- Last resort is debugging**
Needed when effect of bug is distant from cause
Design experiments to gain information about bug
 - Fairly easy, in a program with good modularity, representation hiding, specs, unit tests etc.
 - Much harder and more pain-staking with a poor design, e.g. with rampant rep exposure

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first defense: correctness

Get things right first time
Don't code before you think! Think before you code.
If you're making lots of easy-to-find bugs, you're also making hard-to-find bugs – don't use compiler as crutch

Simplicity is key

Modularity

- Divide program into chunks that are easy to understand
- Use abstract data types with well-defined interfaces
- Use defensive programming; avoid rep exposure

Specification

- Write specs for all modules, so that an explicit, well-defined contract exists between each module and its clients

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second defense: immediate visibility

If we can't prevent bugs, we can try to localize them to a small part of the program

Assertions: catch bugs early, before failure has a chance to contaminate (and be obscured by) further computation

Unit testing: when you test a module in isolation, you can be confident that any bug you find is in that unit (unless it's in the test driver)

Regression testing: run tests as often as possible when changing code. If there is a failure, chances are there's a mistake in the code you just changed

When localized to a single method or small module, bugs can be found simply by studying the program text

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why is this good?

Key difficulty of debugging is to find the code fragment responsible for an observed problem

A method may return an erroneous result, but be itself error free, if there is prior corruption of representation

The earlier a problem is observed, the easier it is to fix

For example, frequently checking the rep invariant helps the above problem

General approach: fail-fast

Check invariants, don't just assume them

Don't try to recover from bugs – this just obscures them

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don't hide bugs

```
// k is guaranteed to be present in a
int i = 0;
while (true) {
    if (a[i]==k) break;
    i++;
}
```

This code fragment searches an array **a** for a value **k**.

Value is guaranteed to be in the array.

If that guarantee is broken (by a bug), the code throws an exception and dies.

Temptation: make code more “robust” by not failing

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don't hide bugs

```
// k is guaranteed to be present in a
int i = 0;
while (i<a.length) {
    if (a[i]==k) break;
    i++;
}
```

Now at least loop will always terminate

But no longer guaranteed that **a[i]=k**

If rest of code relies on this, then problems arise later

All we've done is obscure the link between the bug's origin and the eventual erroneous behavior it causes.

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don't hide bugs

```
// k is guaranteed to be present in a
int i = 0;
while (i<a.length) {
    if (a[i]==k) break;
    i++;
}
assert (i<a.length): "key not found";
```

Assertions let us document and check invariants

Abort program as soon as problem is detected

Use built-in Java assertions, or junit framework

Drawback to built-in: ignored unless **-ea** flag is given

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assertions

If it can't happen, use assertions to ensure that it won't
(*Hunt&Thomas, "The Pragmatic Programmer"*)

Figure out conditions you expect to hold

Then, don't just assume them, assert them

Guidelines

Add assertions as you write, not later

But *not* to check the obvious

```
x = y + 1;
```

```
assert (x == y + 1); // don't do this
```

And *not* to check resource limitations (these are not bugs)

Novices usually under-assert

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responding to failure

How should a program respond to a detected failure?

Try to transparently fix the failure?

- Hard to do, and often just makes problems even more obscure (as we've seen)

Record and Continue?

Abort the program?

- Exactly how to do this is program dependent
- Word processor should offer to save files
- Rocket controller should try to minimize damage

Hard to decide correct action locally

Often want to pass responsibility back to caller

Return null, -1, or other special value to signal error

But this can introduce bugs, silently contaminate data

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exceptions

Exceptions let us bypass normal control flow

No risk of confusion with normal data

Two flavors in Java: checked or unchecked

See **Bloch chapter 8 (#39 – #47)** for best practice

Use an “unchecked” exception if:

There is a convenient way for the client to avoid ever triggering the exception

- So forcing the client to check for the exception is redundant

Or if the exception reflects an unexpected failure

- Nothing the client can reasonably do, e.g. broken rep

Otherwise use a “checked” exception

Compiler forces client to deal with such exceptions

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exceptions examples

E Queue.remove()

throws `NoSuchElementException` [unchecked]

- Retrieves and removes the head of the queue.
- Expects that client will only call method if `Queue` is non-empty, since client can easily call `isEmpty()` if needed
- So forcing client to catch exception would be a burden

FileInputStream.FileInputStream(String name)

throws `FileNotFoundException` [checked]

- Opens a file for input
- Forces client to consider exception, since there is no easy way to check if the file will exist at time of opening (could be deleted externally after any check)

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last resort: debugging

Bugs happen

Industry average: 10 bugs per 1000 lines of code (“kloc”)

Bugs that are not immediately localizable happen

Found during integration testing

Or reported by user

Here's how we deal with such failures

step 1 – Clarify symptom

step 2 – Find and understand cause

step 3 – Fix

step 4 – Do regression

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the debugging process

step 1 – find a small, repeatable test case that produces the failure (may take effort, but helps clarify the bug, and also gives you something for regression)

- *don't move on to next step until you have repeatable test*

step 2 – narrow down location and proximate cause

- study the data / hypothesize / experiment / repeat

- may change code to get more information

- *don't move on to next step until you understand cause*

step 3 – fix the bug

- Is it a simple typo, or design flaw? Does it occur elsewhere?

step 4 – add test case to regression; run regression to see if:

- (a) the bug appears to be fixed

- (b) no new bugs have been introduced

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example

```
// returns true iff sub is a substring of full
// (i.e. iff there exists A,B s.t. full=A+sub+B)
boolean contains(String full, String sub);
```

User reports that method sometimes fails

Points out that it can't find the string “very happy” within:

```
"Fáilte, you are very welcome! Hi Seán! I am very very
happy to see you all."
```

Wrong response:

See accented characters, panic about not having thought about unicode, and go diving for your Java texts to see how that is handled.

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example

Right response – clarify symptom

Find good, simple test case

Pare test down – can't find “very happy” within:

- “Fáilte, you are very welcome! Hi Seán! I am very very happy to see you all.”

- “I am very very happy to see you all.”

- “very very happy”

CAN find “very happy” within:

- “very happy”

Can't find “ab” within “aab”

(We saw what might cause this bug in lecture 3)

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example

Sometimes it is helpful to find two almost identical test cases where one gives the correct answer and the other does not

Can't find "very happy" within:

- "I am very very happy to see you all."

Can find "very happy" within:

- "I am very happy to see you all."

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general strategy

In general: find simplest input that will provoke bug

Usually not the input that revealed existence of the bug

Start with data that revealed bug

Keep paring it down (binary search can help)

Often leads directly to an understanding of the cause

When not dealing with simple method calls

Think of "test input" as the set of steps needed to reliably trigger the bug

Same basic idea

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searching for bugs

Take advantage of modularity

Start with everything, take away pieces until bug goes

Start with nothing, add pieces back in until bug appears

Take advantage of modular reasoning

Trace through program, viewing intermediate results

Can use binary search to speed things up

Bug happens somewhere between first and last statement

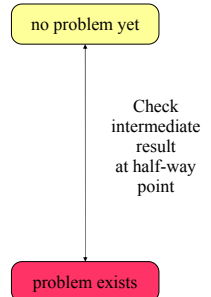
So can do binary search on that ordered set of statements

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binary search on buggy code

```
public class MotionDetector {
    private boolean first = true;
    private Matrix prev = new Matrix();

    public Point apply(Matrix current) {
        if (first) {
            prev = current;
        }
        Matrix motion = new Matrix();
        getDifference(prev, current, motion);
        applyThreshold(motion, motion, 10);
        labelImage(motion, motion);
        Hist hist = getHistogram(motion);
        int top = hist.getMostFrequent();
        applyThreshold(motion, motion, top, top);
        Point result = getCentroid(motion);
        prev.copy(current);
        return result;
    }
}
```

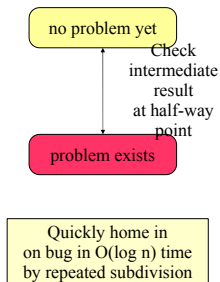


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binary search on buggy code

```
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    private boolean first = true;
    private Matrix prev = new Matrix();

    public Point apply(Matrix current) {
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        Point result = getCentroid(motion);
        prev.copy(current);
        return result;
    }
}
```

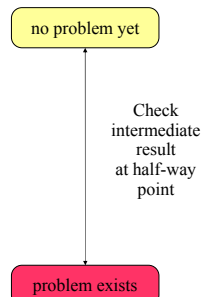


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binary search on buggy code

```
public class MotionDetector {
    private boolean first = true;
    private Matrix prev = new Matrix();

    public Point apply(Matrix current) {
        if (first) {
            prev = current; first = false;
        }
        Matrix motion = new Matrix();
        getDifference(prev, current, motion);
        applyThreshold(motion, motion, 10);
        labelImage(motion, motion);
        Hist hist = getHistogram(motion);
        int top = hist.getMostFrequent();
        applyThreshold(motion, motion, top, top);
        Point result = getCentroid(motion);
        prev.copy(current);
        return result;
    }
}
```

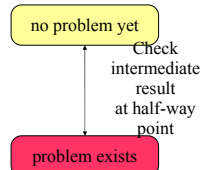


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binary search on buggy code

```
public class MotionDetector {
    private boolean first = true;
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    public Point apply(Matrix current) {
        if (first) {
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        }
        Matrix motion = new Matrix();
        getDifference(prev,current,motion);
        applyThreshold(motion,motion,10);
        labelImage(motion,motion);
        Hist hist = getHistogram(motion);
        int top = hist.getMostFrequent();
        applyThreshold(motion,motion,top,top);
        Point result = getCentroid(motion);
        prev.copy(current);
        return result;
    }
}
```



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regression testing

Whenever you find and fix a bug

- Add a test for it
- Re-run all your tests

Why this is a good idea

- Often reintroduce old bugs while fixing new ones
- Helps to populate test suite with good tests
- If a bug happened once, it could well happen again

Run regression tests as frequently as you can afford to

- Automate process
- Make concise test sets, with few superfluous tests

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keep in mind

The bug is not where you think it is

Ask yourself where it cannot be; explain why

Try simple things first, e.g.,

- Reversed order of arguments: Collections.copy(src,dest)
- Spelling of identifiers: int hashCode()
- @Override can help catch method name typos
- Same object vs. equal: a == b versus a.equals(b)
- Failure to reinitialize a variable
- Deep vs. shallow copy

Make sure that you have correct source code

Recompile everything

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when the going gets tough

Reconsider assumptions

- E.g., has the OS changed? Is there room on the hard drive?
- Debug the code, not the comments

Start documenting your system

- Gives a fresh angle, and highlights area of confusion

Get help

- We all develop blind spots
- Explaining the problem often helps

Walk away

- Trade latency for efficiency – **sleep!**
- One good reason to start early

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Detecting Bugs in the Real World

Real Systems are...

- Large and complex (duh!)
- Collection of modules, written by multiple people
- Complex input
- Many external interactions
- Non-deterministic

Replication can be an issue

- Infrequent bug
- Instrumentation eliminates the bug

Bugs cross abstraction barriers

Large time lag from corruption to detection

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